

TRACE ELEMENT COMPOSITION OF THE MARTIAN SOIL: POSSIBLE COMPONENTS. H.E. Newsom, Institute of Meteoritics, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque NM 87131, e-mail: newsom@unm.edu

Introduction: The major element composition of the Martian "soil" (surficial fines) was determined by the Viking landers, but the trace element composition is still unknown. The soil probably forms by alteration and aeolian erosion of surficial deposits, including glass and shock-activated minerals. In 1997, the Mars Pathfinder mission will provide the first direct measurements of trace elements in the soil by the Alpha Proton X-Ray Spectrometer instrument. The trace element composition of the soil is likely to be quite different from the SNC meteorites, because of chemical transport processes that enrich the soil in mobile elements, such as the S and Cl detected by Viking [1]. Several types of chemical transport mechanisms occurred on Mars. Degassing of cooling magma and hydrothermal alteration driven by volcanism and impact cratering processes transported volatile and fluid-mobile elements and concentrated them into the surficial materials. Another process that can effect the composition of the soil is the input of chondritic material from meteorites and cosmic dust [1]. Compared to terrestrial soils, the martian soils have accumulated over much larger time periods, and the soluble volatile elements will not be removed to sinks because of the general absence of rainfall. Early in Mars history the impact cratering rate was at its highest and this could lead to large chondritic contributions [2], especially if alteration of impact deposits preferentially contributed to the martian soil [3]. Martian impact melts may contain up to 40% projectile material, which is due to low impact velocities [2].

During the early part of Martian history water was more available, leading to giant outflow episodes. Within the outflow channels, excavated outcrops of buried soils may occur. The brief nature of the outflow episodes may have prevented significant leaching of exposed soils except in lakes [4]. During the later history of Mars, volcanism and the deposition of cosmic dust may have been more important as the amount of volcanic and impact activity waned. Deeply buried soils may have been effected by diagenetic processes involving groundwater, which may be responsible for layers visible in the upper walls of Valles Marineris [5]. Thus the nature of soils formed at different times in Mars history may record different trace element signatures. Using the available data, including terrestrial analog data we have calculated possible soil signatures that could be used to identify the origin of different soils.

Degassing and volatile element emissions: Fumarole emissions from volcanoes and lava flows are well known on the Earth (e.g. [6]), and are thought to rep-

resent the degassing of magmas. The existence of degassing pipes in suevite at the Ries Crater [7] suggests similar effects can occur during impact crater formation. Estimating the abundances of such emissions can be roughly approximated by examining the emissions from terrestrial volcanoes. Symonds et al. [6] have estimated the flux of volatile element from the Merapi volcano, Indonesia. To compare this to Mars, which has a different volatile composition, we have corrected the flux for the difference between the Merapi lavas, and the composition of the SNC meteorites. The martian soil contains substantial amounts of S, which we have used to constrain the possible contributions of other trace elements from the normalized flux of volcanic emissions. The results suggest that, if all of the S was from a degassing source, elements enriched by more than a factor of two compared to the abundance of trace elements in SNC meteorites include: S, Br, and Cl. Assuming that most of the S and Cl are lost from the volcanic gas, increasing the contribution of trace elements to the soil by a factor of one hundred, the following elements would also be enriched by more than a factor of two: Bi, As, F, Cd, W, and Zn. Elements that would probably be very enriched by volcanic emissions for which flux information is not available include Au, In, Hg, and Se. Of the possible element enrichments, only S, Cl, F, and Zn have concentrations in SNC meteorites greater than 10 ppm, such that they might be detected in an enriched soil by spacecraft experiments. Based directly on the composition of Hawaiian fumarole deposits, Clark and Baird [1] suggested that martian soils may have high concentrations of Pb, Br, Sb, Hg, and As.

Hydrothermal alteration and palagonitization: The chemical alteration processes effecting minerals and glasses produced by volcanism and large impacts not only provide clays that contribute to the bulk material in martian soils, but also release fluid-mobile elements which can be transported and deposited at the surface in hot springs and fumarole deposits. Boslough and Cygan [8] showed that shock-activated minerals are more easily altered enhancing the effects related to impacts. In general, Si, Mg and Ca are depleted in palagonite, while Fe, Ti and Al are generally unfractionated. With fresh water exposure, Na and K are generally depleted, but these elements are not depleted during palagonite formation in sea water. Similar results have been obtained in experimental alteration of basaltic glasses (e.g. [9,10]). Trace elements from fresh water alteration of basaltic glasses from British Columbia are enriched relative to fresh

basalt for Cs, Ba, Hf, Ta, Th, U and Rare Earth Elements [11]. Other elements, including Sr, Rb, Cr, Co and Ni are variably enriched or depleted in different samples, with a tendency for Co, Ni and Cr to be more concentrated in high-Al palagonites, and depleted in low-Al palagonites. Other studies of palagonitization, by Staudigel and Hart [12], found that the REE's are depleted in marine palagonites, and studies by Furnes [13] of subglacial hyaloclastite from Iceland, found that the elements least affected by alteration are Zn, Ni, Y, Ba and Nb.

Chemical transport within impact crater deposits has not been extensively studied. Transport of volatile elements such as K, Mn and Br has been reported in impact melt deposits from the East Clearwater crater [14] and at Brent Crater [15]. At the Manson crater, alkali elements were lost from porous IMB (Impact Melt Breccia) units, and at the edges of IMB units [16]. New microprobe analyses of the clay vesicle fillings in the suevite from Otting at the Ries crater (Fig. 1) indicate that the clays are substantially depleted in Na, K, P, and somewhat depleted in Ca. Presumably, these elements have been transported away by the fluids which were responsible for the alteration.

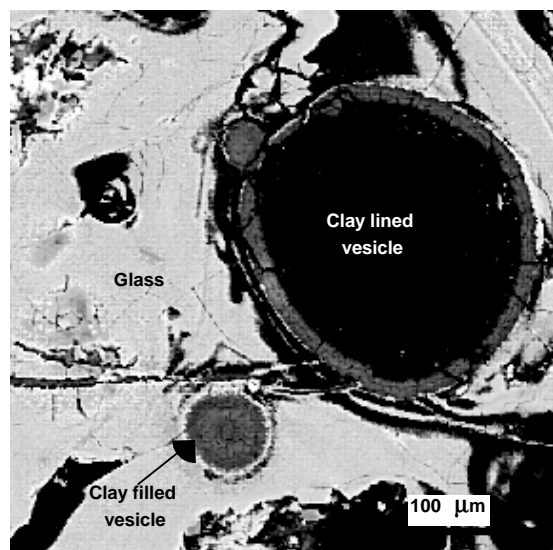


Figure 1 Backscattered electron image of impact melt glass from Otting at the Ries Crater, Germany.

Chondrite additions: The rain of chondritic debris including organic matter [17] on Mars is more intense than at the Earth because of the proximity of the asteroid belt. The chondrites are highly enriched in siderophile elements compared to martian samples because of core formation in Mars. In contrast, the incorporation of achondrite material into the martian soil would not be easily detected, since core formation and degassing also fractionated siderophile and volatile elements in most of the achondrites. Clark and

Baird [18] suggested that a CI component could have been added to the martian soil. Normalizing to the measured S content of the martian soil, if all of the S was from a CI source, elements enriched by more than a factor of two compared to SNC meteorites would include: Ni, As, Bi, Au, S, Se, Ag, Cu, Co, Cl, Br, Cd, Sb, In, and Pb. Of these elements only Ni, S, Co, Cl, and Pb have concentrations in SNC meteorites greater than 10 ppm, such that they might be detected in an enriched soil by spacecraft instruments.

Conclusions: The martian soil contains trace element clues to its origin and age. A high content of siderophile elements relative to SNC meteorites will suggest derivation largely from alteration of impact melt deposits. High concentrations of volatile elements may point to large contributions from volcanic and impact melt degassing, and fumarolic type deposits. The presence or absence of such deposits in the soils from the early history of Mars will bear upon the possible existence of an early wet epoch on Mars. Although the surficial soils analyzed by the two Viking landers suggests a globally mixed aeolian deposit, significant differences may exist between soil deposits in the ancient cratered highlands of Mars, and the younger volcanic terrains of the other hemisphere. Finally, the possible enrichment of the soil in metals, such as arsenic and lead from both fumarolic activity and chondritic debris has implications for the origin of life, and represents a possible hazard to future human exploration.

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